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14. ABSTRACT This letter report summarizes the development and validation of a system that can sample large volumes of water from a ship's ballast system during intake and discharge evolutions, and then return the filtered water to the ballast discharge line. The RDC worked with the Naval Research Laboratory (NRL) in Key West, FL on this effort. NRL modified a preliminary design of a filter skid device that it had previously developed. A prototype unit was developed and deployed on the bulk carrier M/V Indiana Harbor, and commissioning tests of the skid were conducted in Spring 2012.					
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3913/71341012
2012-1574
12 October 2012

MEMORANDUM

From: T. R. Gorton
Technical Director, CG RDC

To: USEPA (GLNPO)

Subj: DELIVERY OF RDC PRODUCT "VALIDATION OF FILTRATION SKID DURING
LAND-BASED & SHIPBOARD TESTS" SUMMARY LETTER (41012) (UDI 1266)

1. The U.S. Coast Guard (CG) Research and Development Center (RDC) is pleased to report its progress in developing technology to obtain representative samples of ballast water discharged by ships. This letter report summarizes our development and validation of a system that can sample large volumes of water from a ship's ballast system during intake and discharge evolutions, and then return the filtered water to the ballast discharge line. The RDC worked with the Naval Research Laboratory (NRL) in Key West, FL during this effort. NRL modified a preliminary design of a filter skid device that it had previously developed. A prototype unit was developed and deployed on the bulk carrier *M/V Indiana Harbor*, and commissioning tests of the skid were conducted in early Spring 2012. NRL has compiled the results of this successful effort into a manuscript being prepared for submission to the Journal of Plankton Research¹ where it is expected to receive broad scientific readership. The skid is now undergoing operational testing by a third party on board the *Indiana Harbor* as it operates in the Great Lakes.

2. Efforts to reduce the transport and introduction of non-indigenous species into United States waters include CG promulgating a standard for allowable concentrations of organisms in ships' discharged ballast water. For organisms greater than 50 micrometers (μm) (nominally zooplankton, but also including protists and micro-invertebrates), fewer than 10 organisms per cubic meter (m^3) of ballast water may be discharged. In the course of developing a protocol to test the efficacy of Ballast Water Treatment Systems (BWTS) and their ability to meet the discharge standard, it was determined that relatively large sample volumes (i.e., cubic meters) would need to be drawn and analyzed to evaluate the sparse concentrations of organisms expected following successful treatment. The current practice for sampling living organisms in ballast water is to concentrate organisms from the discharge stream using plankton nets - both at land-based ballast water test facilities and during shipboard testing. For shipboard applications, this method can be impractical since it can require a large operating space, the plankton net setup is susceptible to overflows, and disposal of the wastewater can be problematic.

¹ First MR, Lemieux EJ, Hyland WB, Grant JF, Moser CS, Riley SC, Robbins-Wamsley SH, Steinberg MK, Wier TP, Drake LA (2012) Validation of a closed-housing filter skid for in-line sampling of aquatic organisms. *Journal of Plankton Research* 34:321-331.

3. To address these problems, NRL developed a prototype filter array (i.e., a filter skid) of closed, pressurized filter housings, each fitted with a net constructed of 35- μ m mesh (resulting in a 50- μ m diagonal opening). The goal was to design a straightforward system capable of sampling water with a biological capture efficacy equal to or greater than that of a plankton net but that accommodated the restrictions specific to shipboard installation and operation. The RDC used Great Lakes Restoration Initiative (GLRI) funds to modify, construct, and test the NRL prototype against the plankton net method on shore with marine organisms and aboard the *Indiana Harbor* with freshwater organisms. This prototype of a shipboard filter skid (p3SFS) contains two filter housings arranged in parallel and includes a ‘drip sampler’, i.e., a port immediately upstream of the filter housings used to collect a composite whole (unfiltered) water sample from which smaller organisms may be quantified. This version of the filter skid, photo included as enclosure (1), was constructed and validated at the NRL land-based test facility in Key West and was subsequently installed and tested aboard the *Indiana Harbor* operating in the Great Lakes. The *Indiana Harbor* is owned and operated by the American Steamship Company, which was most helpful and accommodating during the conduct of this project.

4. The p3SFS filter skid was developed specifically for the *Indiana Harbor*, which is being used as a test platform for another, related GLRI-funded effort. The skid was designed to continuously draw sample flow from a port in the ship’s ballast header, concentrate organisms in the water through the pair of filter housings, and then return the filtered effluent into the same ballast header. The p3SFS provides a touch-screen control interface through which a user enters the desired operational flow, sample volume, and sampling duration; the user is then guided through steps to ready the system for sampling. The filter skid’s controller initiates flow by activating a centrifugal pump and sends position commands to a control valve to maintain the user-specified flow rate. The user can monitor the operation status using the real-time display of key sampling parameters from sensor outputs that are logged every second and can be extracted for analysis after the operation is completed. Once a condition specified by the user (i.e., sample volume or duration of sampling) is achieved or a critical alarm is triggered (e.g., a high pressure drop across the filter housings due to clogged filter bags), the controller closes all valves to isolate the sample in the filter housings and then deactivates the pump. All of the components are housed in a rigid steel frame that provides mobility and structural integrity as the unit is temporarily integrated into the ship’s ballast system.

5. The shipboard filter skid was tested against the more traditional plankton net sampler at the NRL test facility in Key West in February 2012. The p3SFS and the plankton net (PN) were set up to sample ambient Key West water simultaneously from two sample ports in the test facility piping. Prior to test initiation, known quantities of polystyrene microbeads (50 μ m diameter) were added to each filter housing and to the PN to evaluate the retention ability of the sampling devices and to determine the sensitivity of detection of the analysts. A total of six successful experiments using the two separate sampling ports were conducted; three experiments from each port for each sampling device. Biological samples from the p3SFS, the PN, and the drip sampler (whole water sample) were compared for organism concentration, community composition, and mortality. No significant difference was found between the p3SFS and the PN for these three factors. Mortality varied between replicate experiments and overall was lower for the PN than for the p3SFS, but the difference was not significant. Likewise, the recovery of microbeads did

not differ significantly between the p3SFS and the PN. There was no significant difference between analysts' counts of live organisms in the p3SFS or the PN. The tests also revealed that the individual housings of the p3SFS did not significantly differ in their performance, which indicates the samples from the individual housings can be pooled into a single sample. The experiments showed that the p3SFS performed comparably to the PN and therefore that the p3SFS is well suited for shipboard testing.

6. The p3SFS was installed and commissioned aboard the *Indiana Harbor* in early May 2012. Three successful sampling events occurred over the course of a single deballasting operation aboard the vessel. The sample flow rate through the p3SFS (automatically logged every second) was relatively constant around the target flow rate of 50 gpm (189 L min^{-1}). The differential pressures across each filter housing (also logged every second) were all lower than 4.5 psi (31 kPa). For biological analyses, samples collected in the two filter bags were pooled into a single sample and compared to a sample of whole water collected from the drip sampler. Although the volumes of the samples differed (total water volume filtered through both filter bags was $4.8 - 5.1 \text{ m}^3$, and the volume collected by the drip sampler was 4 – 5 liters), it was possible to compare the mortality and the community composition between the samples. Mortality was $< 3\%$ for both p3SFS and drip sampler. Organisms were active and there was no evidence that the p3SFS damaged the organisms (severed appendages, etc). Additionally, there was no qualitative difference in the community composition between the filter bags and the drip sampler indicating that the p3SFS did not selectively retain sub-populations of this size class. In both cases, the community of living organisms $\geq 50 \mu\text{m}$ was dominated by soft-bodied organisms (rotifers and ciliates). The highest concentration of organisms occurred during the last hour of deballasting (with the tank nearly drained). In that final sampling event, high concentrations of living, motile organisms (more than $2 \times 10^5 \text{ individuals m}^{-3}$) were recovered, demonstrating the p3SFS is capable of capturing relatively small (50 – 100 μm), soft-bodied organisms. Based on these data (and the results from land-based trials), the p3SFS is a valid device for collecting samples from an in-line flow stream, such as piping used to transport ballast water aboard ships.

7. One concern voiced at the beginning of this project was that the p3SFS could sample different organism communities with different capture efficiencies. Specifically, the marine community sampled at NRL was dominated by hard-bodied organisms such as copepods (which are crustaceans) whereas the freshwater community in the Great Lakes is often dominated by soft-bodied organisms such as rotifers and ciliates. The concern was that higher differential pressures would exist across the closed filter chambers that could either force the soft-bodied organisms through the mesh, lowering the capture efficiency, or damage organisms resulting in a higher mortality rate. During the shipboard sampling in Superior Harbor, the community composition of samples from the filter bags and the drip sampler (whole water) was compared. No qualitative differences in the composition or quantitative differences in mortality were observed, indicating that the p3SFS is highly effective in capturing soft-bodied organisms and is suitable for both types of communities. Additional comparison of the p3SFS and a portable PN device is planned by another group conducting research aboard *Indiana Harbor* under separate funding.

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TESTS” SUMMARY LETTER (41012) (UDI 1266) 12 October 2012

8. The results of this research effort have shown that the p3SFS is a practical solution for sampling large volumes of water aboard ships. The use of an in-line sampling device such as the p3SFS is called out in the EPA’s Environmental Technology Verification Program’s current draft of a generic protocol for verification of BWT technologies aboard ships. The basic design and information for constructing a filtration skid are publicly available from NRL and can be modified as necessary for specific ships and ballast systems. Reports resulting from this project that are available to the public include:

- a. Drake LA, Wier TP, Moser, CS, and Grant J (2011) Trip Report: Visit to the American Steamship Company’s M/V *American Integrity* and M/V *Indiana Harbor* for the Shipboard Approval Filter Skid Project. Letter report 6130/1230 published 21 December 2011 by the Naval Research Laboratory, Washington, DC.
- b. Drake LA, Moser CS, Wier TP, and Grant JF (2012) Generic Protocol for the Use of a Filtration Skid (p3SFS) During Shipboard Approval Tests of Ballast Water Management Systems. Letter report 6130/1221 published 30 May 2012 by the Naval Research Laboratory, Washington, DC (Available as RDC Product “Generic Protocol for Use of Filtration Skid During Shipboard Approval Tests of Ballast Water Treatment Systems”, UDI 1267, 8 June 2012).
- c. Drake LA, Moser CS, Wier TP, and Grant JF (2012) Ship-Specific Protocol for the Use of a Filtration Skid (p3SFS) During Shipboard Approval Tests of Ballast Water Management Systems. Letter report 6130/1222, published 30 May 2012 by the Naval Research Laboratory, Washington, DC.
- d. Drake LA, Moser CS, Wier TP (2012) Trip Report: Visit to the American Steamship Company’s M/V *Indiana Harbor* to Install and Commission a Shipboard Filter Skid (p3SFS) (To be issued to the R&D Center but currently under review at NRL.)

9. The RDC plans to make this summary report and enclosure (1) available to the public by publishing it with the National Technical Information Service, via Defense Technical Information Center (DTIC). If you would like to comment and/or request changes to the report prior to publishing, or do not want the report to be published, provide your comments on the enclosed concurrent clearance form, enclosure (2), within 30 calendar days from the date of this letter.

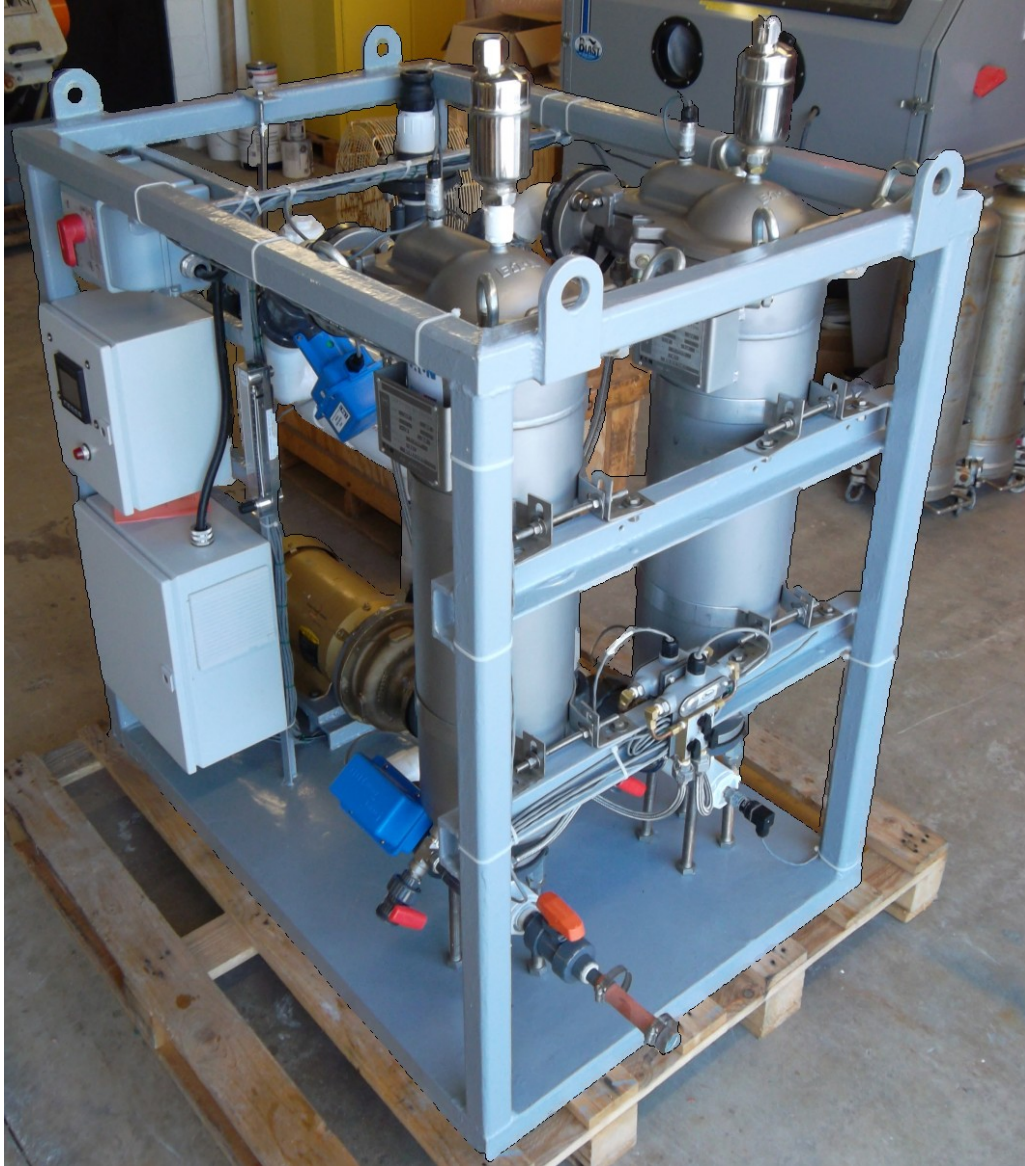
10. The R&D Program is committed to delivering quality, timely products to our customers. We would greatly appreciate your comments on how we are doing. Please take a moment to complete and submit the enclosed Product Evaluation Tool form, enclosure (3).

11. It has been a pleasure working with your staff on this effort and we look forward to future collaborative efforts. If you have any questions, the RDC project point of contact is Ms. Penny Herring, (860) 271-2868, Penny.R.Herring@uscg.mil or Mr. Chris Turner, (860) 271-2623, email at A.Chris.Turner@uscg.mil.

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Enclosure: (1) Photograph of the p3SFS
(2) Concurrent Clearance form
(3) Product Evaluation Tool form

Copy: COMDT (CG-926)
COMDT (CG-OES-3)



Photograph of the p3SFS showing filter housings, power box, controller, and main disconnect switch. Components are identified and details of the operation are provided in Drake et al., 2012.